InLCA: Case Studies – Using LCA to Compare Alternatives

# The Ecology of Scale: Assessment of Regional Energy Turnover and Comparison with Global Food*

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**Abstract**

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**Goal, Scope and Background.** Obviously, people assume that the regional production and distribution of food requires less energy turnover, compared with global transports of food. Politicians claim the term 'regionality', maintaining that regionality is a medicine against wasting so much energy for the global food distribution. Additionally the energy turnover is causing pollution. But remarkably, there is a lack of empirical data to support this idea. At the same time, nobody really requires regional origin for non-food items, e.g. for bicycles, dishwashers, furniture or cars etc. The public mainstream asks for regional origin merely for food. Hence, the first scientific issue worked out in this paper is how the energy turnover of comparable food items can be measured, regarding the lifecycle of food in total. That means to investigate the partial systems of crop or breed, of food production, of packaging including transport and distribution up to the point of sale. Secondly, it has to be checked, if the assumed coincidence of low energy turnover and regional origin can be verified.
The specific energy turnover, calculated in the unit [kWh per kg] or [kWh per l] of food, is investigated by comparing regional with global process chains for different food items. Two examples of food – fruit juices and lamb meat – are researched, by personal investigation worldwide. Firstly, fruit juices of high grade quality from Brazil, from European origin and from local German farmers are compared, in terms of energy. Secondly, a comparison of lamb meat from New Zealand and lamb meat from local German farmers is conducted. Lamb meat has been investigated, because it is shipped around the world as frozen natural food, not concentrated like juices. In addition, the business size of the food producers is researched for both examples.

**Methods.** As a part of LCA the energy turnover of each process step from the very beginning up to the point of sale is investigated. These primary results are the basic empirical data, in order to allocate the energy turnover at the food items as functional units. The results of regional, European-continental and of global process chains are compared. In addition, the issue is investigated, whether the specific energy turnover depends upon the business size.

**Results and Discussion.** Surprisingly, the data in both cases demonstrate a strong degressive relation of the specific energy turnover and the business size. Here it is not important, if the business is regional or not. Merely the efficiency and logistics of the production and the operations determine the specific energy turnover. These findings seem closely connected with the business size, because small companies are not able to invest in energy recovering and saving technology. The regional juices business is worsened by the huge number of small-sized transports of the crop and the nearly bottle-wise distribution. Regarding lamb meat we once more find the disadvantages of comparably small farms again. In addition, the German farmers need daily shepherds, fences by night, stables and usually additional feed during the wintertime. All these efforts are not necessary in New Zealand, where the climatic conditions and the open countryside with low population allow rather easy and low energy breeding of lamb.

**Conclusion.** The coincidence of economic and ecological facts is obvious. As a matter of fact, in economics there is a strong degressive relation between the production costs and the number of produced items. This relation is very well known as 'Economy of Scale.' Our findings lead to similar conclusions, in terms of ecology. That means, the production ecology depends on the number of produced items. Additionally, our results demonstrate a minimum business size, so that we can claim an 'Ecology of Scale' as well.
However, on the other hand, the reported data and the conclusions are valid for the investigated food items – fruit juices and lamb meat – only. Nevertheless, one conclusion is already evident: The most popular claims for regional food production and distribution instead of global process chains are not generally valid. Small farmers basically need much more energy to produce and distribute their products, compared with bigger units. Both food items demonstrate clearly, that the ecological quality is mainly influenced by the operational efficiency and not by the marketing distance itself.

**Recommendation and Outlook.** Much more detailed data of all the investigated operational units, processing fruit juices and lamb meat, have been published (Fleissner 2001). As a further example, we investigate wine from different countries as a further example. Different from fruit juices, which can be shipped as a concentrate, and different from lamb meat, which is shipped as frozen food, wine of high grade quality is always bottled close to the place of origin. That means, that not only the food, but also the heavy weight packaging is transported around the world. So, we are very curious about the results, which we expect for 2004.

**Keywords:** Business size; chains; comparable process; ecology of scale; fruit juices; lamb meat; marketing distance; operational efficiency; regional and global food items; specific energy turnover

## Introduction

Usually people assume that regional production and consumption of food require all over less energy than global processes of food distribution. To verify or falsify this statement by empirical data and further to improve the used method of Life Cycle Assessment, a scientific evaluation of specific energy turnover of food production and distribution is applied, comparing regional with European-continental and global food processes. The purpose of the study is to observe whether the operation efficiency and the logistics are more important than the transport distances as such, regarding all the specific energy efforts of the whole process chain.

Using the energy component of Life Cycle Assessment (LCA) as standardized method the energy efforts of the whole process are identified and allocated to the food items as functional units. LCA is defined as a comparison of the environmental impacts of two or more different but comparable products, processes or systems (UBA 1992). The method is meanwhile published as standard (DIN EN ISO 14040 ff).

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Parts of LCA are energy balances. The turnover of energy in all steps of the process is to evaluate first and then to allocate to the functional unit. Primary energy and environmental impacts can be calculated from this data base.

## 1 State of Science and Hypothesis

Scientific publications indicate the conception of regional produced food items being more ecological than global distributed consumer goods. As an example, Weizsäcker uses orange juice and indicates a consumption of 40 million liters of gas only for the transport from Brazil to Germany. He recommends the consumption of red currant juice made from regional German crop instead of orange juice made from Brazilian concentrate. This replacement would cause less energy turnover and, at the same time, provide the population with more vitamins. Besides the fact of missing capacity of red currant crop throughout the year, the publication does not indicate the used scientific method and gives no empirical data for the published findings (Weizsäcker 1995).

Kranendonk is researching water and energy turnovers using fruit juices from a Brazilian origin as well. The publication reports about 22,458 kg water and 139 kg gas per ton fruit juice. Unfortunately, the origin of the data and the way of allocation remain uncertain (Kranendonk 1993).

A Swiss research project is estimating the turnover of primary energy and the release of carbon dioxide for the production and distribution of lamb meat from New Zealand. These results are compared with Swiss lamb meat. This direct comparison is made possible, because the data for the breed and slaughter of the lamb, as well as the circumstances for packaging and storage of the meat are assumed to be the same for lamb meat from Swiss and New Zealand. Only transportational data are different. Therefore, the data base remains uncertain (Zamboni 1994).

Jungbluth provides a comprehensive overview regarding these kinds of research studies. Unfortunately, there is no more specific information on fruit juices or lamb meat in this publication (Jungbluth 1998). Due to the assumption that regional food distribution is involved with lower energy turnovers and smaller resource inputs than global interactions, v. Koerber prefers regional consumer goods. In addition, he asserts lower emissions of environmental impacts and, as well, claims better economics on average, because of smaller marketing distances. Nevertheless, there is still a lack of specific empirical data to prove these conclusions (Koerber 1999). In sum, although the conclusions are not empirically supported, the consumption of food from regional crop and breed is supported.

The present research started in 1997, followed the assumption that not only transportation and distribution distances but also efficiency and sophisticated logistics of the whole business are decisive for the specific energy turnover of different food items. A global acting enterprise could possibly be more efficient in terms of energy than a local farmer, in spite of global distances. This hypothesis was formed comparing food with non-food items, due to the fact that, e.g., detergents, clothes, household machines, dishes or furniture are always produced and distributed regarding only the economic and not the regional point of view. Nobody ever demands regional production for non-food, but only for food items.

In detail, today we have empirical data available:

- of fruit juices from Brazil and different European countries including Germany and
- of lamb meat from New Zealand and Germany.

Both examples were selected to include typical different food items into this investigation. Juices from global and European continental origin (Brazil, England, Poland, Italy and Germany) are concentrated under supply of energy: The concentrate is stored and shipped at –10°C, covered with nitrogen. Finally the concentrate is diluted in Germany using purified drinking water. This product is distributed using refill bottles. Finally, consumers get a high-grade standardized juice throughout the year, made from the origin without any additives except of high quality drinking water (needed for dilution). Lamb meat, however, is a natural product which cannot be concentrated. About 60% of the yearly consumption of lamb meat in Germany originates from New Zealand as frozen food, and about 40% comes from local German farmers. For both cases we know the exact transport and distribution paths. Therefore, the energy turnover can be allocated for each step.

## 2 Fruit juices: Process Steps and Research Details

The investigation starts with different producers of orange and apple juices in Germany, drawing out a list of energy turnover per year for manufacturing, transportation and distribution. Due to a cooperation with diluting companies, importers of orange juice concentrate (OJC) located in Rotterdam and Antwerp are included into this investigation. Step by step all the shippers via land and sea can be identified and evaluated. The final step includes the assessment of farmers and the squeezing and concentrating facilities in Brazil.

The Brazilian crop in the state of Sao Paulo is transported from the plantations to the squeezing and concentrating facilities by truck, covering a distance of 80 km on average. The primary juice is concentrated with a vacuum cross-flow rectification from 11 to finally 66 brix[1]. This concentrate can be stored and shipped easily, at –10°C under nitrogen; it is then stable for about half a year. It is shipped by special trucks to the seaport of Santos, 400 km away from the concentrate production. The sea transport from Santos to Rotterdam or Antwerp takes 13 days using special 16,000 tons vessels carrying 40 containers with 400 tons OJC each. These containers are used for this purpose only. After unloading in Rotterdam or Antwerp they are replaced by empty containers at once and the vessel goes immediately back to Santos under some water ballast, taking on only 11 days for return.

Calculating the vessel capacity, it is evident that one vessel carries 16,000 tons of OJC which is equivalent to 100,000 tons or 100 million liters of orange juice, after diluting. These figures illustrate that only 8–10 vessels per year are sufficient to provide the whole German population (82.5 million people) with orange juice. The final road transport to the German diluting companies adds up another 400 km on average, using trucks with 25 tons OJC. The gas for all returns has to be allocated to the specific energy turnover of the juices, because all the shippings go back without any load except some water ballast.

With this information, allocation problems of LCA can be solved easily, because we have valid data for all parts of the

[1] brix: abbreviation of the German term '**Br**echungs**i**nde**x**' as concentration unit for juices, measured by a refractometer.

total system, consisting of plantations and the crop, squeezing, concentrating and rediluting facilities including all specific transports and distributions up to the point of sale in Gießen, Germany. Cooling of the 400 tons OJC containers at the European seaports and even the return of the refilling bottles and their purification are included as well. The final results are referred to 1 liter of fruit juice (Fleissner 1999).

Secondly, data of apple juices from European-continental origin are taken into account. Here, we usually find two types of concentrate with 22 and 66°brix, also made as well from primary juice with 11°brix by cross-flow vacuum rectification units. Those concentrates are shipped to the diluting companies. There, purified drinking water is used to dilute the concentrates. After bottling the juice it will be distributed to the points of sale. Countries of the crop origin are Poland, Great Britain, Italy and Germany.

Thirdly, we have many data from local farmers around Gießen, who transport their apples to small squeezing facilities inside the region. The farmers get vouchers for a part of the juice and can pick up juices without payment from the squeezers. This signifies a cash-free system, typical for small areas and short distances. The smallest squeezing facility investigated in this study had only a few suppliers of apple crop, the biggest squeezing facility more than 100 suppliers of apple crop in the area around.

Methodologically, it turned out in all cases that it is very important to visit all the contact partners in person and to evaluate each of them separately by interviews and copies of energy bills. That means that this investigation took place in Brazil in the State of Sao Paulo, at the ports of Santos, Rotterdam and Antwerp, even on the vessels talking to the engineers on board as well as to obtain all primary information needed.

## 3 Fruit juices: Results and Discussion

The researched primary data, given in tons or liters of gas, m³ natural gas or kWh electricity, are converted into terms of energy, using their heat values. These results are allocated to the functional unit, here defined as 1 liter of fruit juice at the point of sale. Finally, the specific energy turnover in kWh/l is recorded as a function of the yearly throughput of the squeezing facility in tons/year, using a logarithmical scale covering the wide range of the investigated companies. **Fig. 1** shows the energy results for the production units. **Fig. 2** adds the energy turnover of transportations and distribution therefore providing an entire overview.

In Fig. 1 it is shown very clearly that small companies with up to 100 tons of fruit squeezing per year face disadvantages – with a specific energy turnover range from 1.1 to 2.5 kWh/l. The small companies build a cluster of coordinates below 100 tons per year. Another cluster can be seen on the right side of the diagram: Companies with more than 2000 tons per year are showing less than 0.5 kWh/l specific energy turnover. In general, we find a strong degressive function indicated by an interpolation line.

The idea of changing this degression into a progression by adding the energy efforts for the global transport is proved in Fig. 2. Here, all the energy terms of transportation and distribution are added to the data set of Fig. 1. The cluster of small companies increases to values of 1.5 to 3.2 kWh/l. At the same time though the cluster of bigger companies increases only to

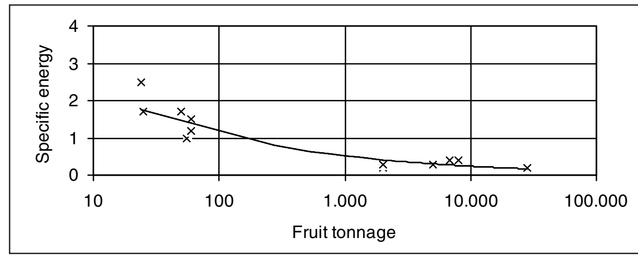


**Fig. 1:** Specific energy turnover in kWh/l versus fruit tonnage in tons/a: production only (marked by x)

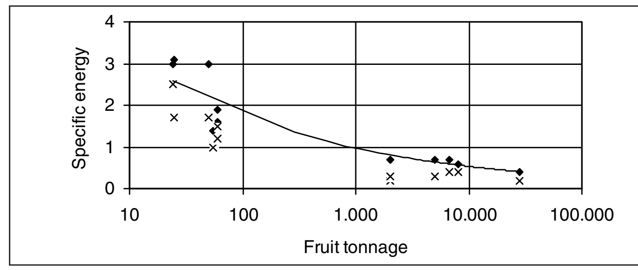


**Fig. 2:** Specific energy turnover in kWh/l versus fruit tonnage in tons/a: Production (marked by x) plus transports and distribution (marked by ♦)

values of 0.4 to 0.7 kWh/l. The interpolation of these entire results gives again a strong degressive function (Schlich 2000).

The assumption of changing the advantage of global business into a disadvantage because of the global transport energy is clearly falsified. Transportation and distribution efforts of small companies are even higher than those for global food transportations. As clearly demonstrated small fruit companies need approximately 0.5–0.8 kWh/l for transportation and distribution, but surprisingly the global transportation takes just 0.1–0.3 kWh/l despite immense distances. Based upon primary data of all global and regional process steps it can be concluded that the specific energy turnover of fruit juices produced from small companies turns out to be higher than comparable fruit juices from companies with more than 2,000 tons per year, in all investigated cases.

## 4 Lamb Meat: Process Steps and Research Details

As mentioned before, approximately 60% of the yearly German consumption of lamb meat is produced in New Zealand and shipped as frozen food to Germany, unloaded at the seaport of Hamburg. About 40% of the consumed lamb meat derive from regional origins of the German countryside.

The data research of the New Zealand process starts at the place of origin by personal evaluations of farms, slaughtering, dissecting and freezing companies and shippers. Also here, all singular transportations from the farms to the seaport of Lyttleton (South Island of New Zealand) are included. The shipment from there to Hamburg takes 30 days. The lamb meat is deeply frozen at –30°C and stored into reefers (type 1CC) as standardized containers. The reefers are switched to cooling air on board of the vessel. The cooling system on board is energized by gas providing a compressor drive.

The vessel carries 1,403 reefers loaded with different goods, mostly lamb and cattle meat, furs and wool, all natural products of New Zealand. 97 reefers are bound for Hamburg, carrying 2,066,100 kg lamb meat (net weight). The container ves-

sel leaves Lyttleton eastward bound for Hamburg, usually via Port Chalmers (North Island of New Zealand), Santos (Brazil), Lisbon (Portugal), Zeebrugge (Belgium) and Tilbury (Great Britain). At each port some containers are unloaded, some others loaded. After reaching the final destination Hamburg the vessel returns immediately back home to New Zealand – via LeHavre (France), Dakar (Senegal), Cape Town (South Africa), Perth and Sydney (Australia) – fully loaded with European export goods.

After a 2-month time period the trip around the world is repeated. By getting all the data of loading and unloading the vessel including all timetables, unload and load lists and the refuelling of the vessel it is possible to allocate the entire energy turnover of the overseas transportation and cooling efforts to the functional units (Fleissner 2001).

Before loading and after unloading at the seaports the reefers are stored at the seaport. To guarantee a continuous cooling the reefers are equipped with standardized backpacking cooling systems, using a 400 V power supply. Similar systems are used on the trucks to continue the cooling process up to the point of sale wherever that is. All components of this transportation and cooling technology are established and standardized worldwide to ensure an uninterrupted cooling process. Keep in mind, the seaports do not need any cooling storage facilities for the New Zealand lamb meat, due to an existing backpacking technology for the reefers.

To compare regional with global organized distributions we investigated local German farmers around the countryside, again, by personal interviews of farmers and shepherds, visiting places of breed, slaughter and dissectioning as well as researching the structure of regional marketing. Only with this intensive research it is possible to present valid data for the assessment of the specific energy turnover of regional process chains. In comparison to the New Zealand process, shepherds are necessary in Germany. Here, the sheep are guarded all day long and kept in fences during the night. Usually, German sheep are kept inside the stables for five months of the year, providing the herd with water and feed. This intensive proceeding of lamb meat production – with energetical expenses for daily shepherds, stables and additional feed in the wintertime – is only necessary in Germany, but not in New Zealand. One reason for that can be found in climatical differences between Germany and New Zealand. Secondly, the small density of population in New Zealand and the open countryside allow easy breeding of lamb in that country down under. In Germany, the shepherds usually take their car to go to work. The additional efforts of daily shepherding in Germany and fencing in at night must be taken into account and added up to the specific energy turnover.

## 5 Lamb meat: Results and Discussion

The reported data are researched again for one year of production and allocated to the functional unit of 1 kg lamb meat ready to consume. Thereby we get the yearly specific energy turnover in terms of kWh per kg. **Fig. 3** shows the results for production units dependent of the production throughput per year. **Fig. 4** adds the energy turnover of all the transports including the distribution to the point of sale.

Once again we find a degressive logarithmic function indicated by the interpolation line. It is remarkable that small farmers require more specific energy than bigger units. The New Zealand farmers are able to produce lamb meat with only small expenses of energy. The idea of changing these results for the benefit of the small local farmers is demonstrated in Fig. 4. Here the energy expenses for the global transportation are added. Altogether, the global as well as the local transportation and distribution efforts are considered in Fig. 4.

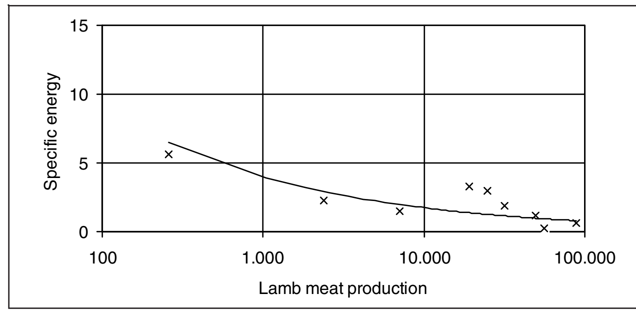


**Fig. 3:** Specific energy turnover in kWh/kg versus lamb meat production in kg/a: Production only (marked by x)

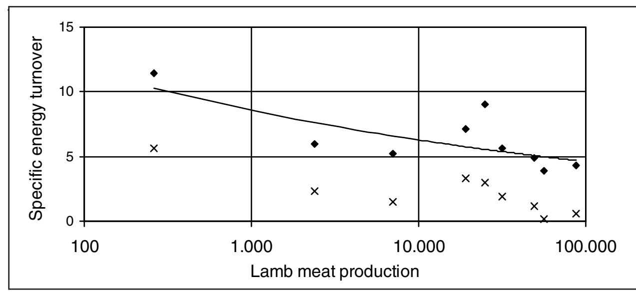


**Fig. 4:** Specific energy turnover in kWh/kg versus lamb meat production in kg/a: Production (marked by x) plus transports and distribution (marked by ♦)

Surprisingly, the investigated data of lamb meat demonstrate clearly two facts: first of all, the specific energy turnover is again dependent on the business size, as seen before with the data of fruit juices; secondly, the sea transportation – under strict cooling conditions in accordance to HACCP (Hazard Analysis Critical Control Point) – takes in the long run less energy than local transportation and distribution efforts.

## 6 Conclusion

The recorded data of fruit juices and of lamb meat demonstrate a strong relation of the specific energy turnover and the business size. Here it is not important if the business is a regional one or not. Just the efficiency and logistics of the production and the operations determine the specific energy turnover. These findings seem closely connected with the business size, because small companies are not able to invest in energy recovering and saving technology. The regional juices business in Germany is frequently worsened by the huge number of small-sized transports of the crop and the nearly bottlewise distribution.

But we have to be careful: Our findings help to identify regional business units, which are very effective as well, in terms of energy. One of the coordinates in Fig. 2 (0.7 kWh/l at 2,000 tons/a) represents such a regional business, which is able to compete with global business data. The presented data lead us to a business size of at least more than approximately 1,000 tons/a, which seems to be necessary to guarantee an effective

regional operation. This can be considered as a 'break even point' in the ecology of scale. Hence, the results are not to be misunderstood as arguments against regional food business. But the findings can give indications and advice for the improvement of regional business, e.g., by founding cooperative organizations for earning the crop or marketing the juices.

Lamb meat has been taken into account because it is shipped round the world as frozen natural food, not concentrated like juices. However, we find the disadvantage of comparably small farms again. Here the bad climatic conditions in Germany worsen the energy balance, because of the necessity of stables and additional feed during the wintertime. In New Zealand, daily shepherds, fences by night, stables and usually additional feed are not necessary. Unfortunately, German farmers don't have an effective regional transportation and marketing organization at their disposal. They market their products by themselves, joined with comparably huge energy efforts. These facts are demonstrated both at the local lamb and the juices business.

A calculation illustrates the disadvantages, small farmers are facing: If a local juice squeezer takes his car only 10 km one way to sell 100 liters of fruit juice he will spend approximately 2 l of gas for this business. That seems not much, but it burdens the energy turnover with 20 kWh on total or 0.2 kWh per liter of fruit juice. Remarkably, this is about the same specific energy turnover, which is necessary for the OJC-transport from Brazil to Germany, despite of the 10,000 km distance. Hence the advantages of the global high-effective business operations are evident. In sum, regional German farmers have to improve their energy management. If not, they are not competitive, at least not in terms of energy. Particularly, the food items they sell cannot claim the label of organic or ecological origin, because of wasting so much energy.

For that reason, operational units in all cases require a minimum size, to be competitive and to obtain ecological quality, in terms of energy turnover. Obviously, these findings are comparable with non-food items and – by the way – well known from the economic point of view. Furthermore, the coincidence of economic and ecological facts is obvious. As a matter of fact, there is a strong degressive relation between the production costs on the one and the number of produced items on the other hand. This relation is very well known in economics, named as economy of scale. Our findings lead to similar conclusions, in terms of energy turnover. That means, the production ecology depends on the number of produced items as well.

So we have to claim an 'Ecology of Scale', leading additionally to a minimum size of food business. Below that size, a food producer or operational unit cannot utilize its capacity in order to obtain a good ecological quality of food. Therefore, it is evident that the results are not to misunderstand as a final speech against regionality and small transport distances. Moreover, the findings demonstrate very clearly the necessity of good logistics and efficiency, to operate regional food business (Daly 1996, Daly et al. 2003, Hammer et al. 2003).

But, on the other hand, the reported data and the conclusions are valid for the investigated food items – fruit juices and lamb meat – only. However, one conclusion is already evident: The most popular claims for regional food production and distribution instead of global process chains are not generally valid. Basically, small farmers need much more energy to produce and distribute their products, compared with bigger units. Both food items demonstrate clearly, that the ecological quality is mainly influenced by the operational efficiency and not by the marketing distance itself.

## 7 Recommendation and Outlook

Far more detailed data of all the investigated operational units, processing fruit juices and lamb meat, are published (Fleissner 2001). Actually, since 2002 we are investigating wine production, bottling and delivery as a further example of food. High quality wine is bottled at the places of origin, e.g., in South Africa, California, Chile, Australia and France, or at different regions in Germany. Maybe, the worldwide shipping of the bottles burdens the entire energy balance, differently to fruit juices and to lamb meat without heavy packaging. This question will be answered soon. However, one conclusion has already become evident: the most popular claims for regional food production and distribution instead of global process chains are not generally valid.

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